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# Neutral Reference Model for Engineering Change Propagation in Global Top-down Modeling Approach

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**Abstract – As the modular production is an important issue in globalized manufacturing industries, sub modules or parts of the final product are provided by many suppliers. Some part suppliers design their own products for themselves. In some cases, part supplier may provide the same type product to multiple 1-tier companies. Because all suppliers and 1-tier companies can not use the same CAD system in general case, the engineering change in the CAD model of one company could not propagate to related CAD models of other companies directly. Although they use the same CAD system, it is hard to share their CAD model with each other because of company security policy. In this paper, the neutral reference model, which consists of the neutral skeleton model and the external reference model, is proposed to apply a global top-down modeling approach to collaborating companies.**

***Keywords*: Collaborative engineering, Engineering change, Neutral skeleton model, External reference model, Neutral reference model, Top-down modeling**

## 1. Introduction

In most general manufacturing companies, the production of many parts and sub-assemblies are committed to part-suppliers. The most common components, such as motors, switches, connectors, springs, bearings, and LCD panels, are developed and produced by part-suppliers using their own technology and knowledge which are independent of the first tier companies. Due to the recent trend of commodities becoming highly accumulated, compact, and comprising many functions, the commodities' sub-modules also need many R&D and knowledge resources regarding design and manufacturing. Many part-suppliers have specialized technologies and experience related to their products, and thus, the first tier companies depend on part-suppliers' collaboration.

Following this trend, the current production system has become globalized and modularized. For example, a sub-module produced by a part-supplier could be supplied to not only one first tier company, but also rival first tier companies.

Furthermore, it is not unusual for part-suppliers to design their own parts for themselves. Because such design information is managed as part of company's intellectual properties, it is difficult to provide that information to the first tier company. Similarly, the first tier company can not provide all the information about the final product to the part-suppliers.

Nowadays, 3D CAD systems are applied in the design process for mechanical products and structures. Although 3D CAD systems have many advantages, there are four primary problems concerning collaborative design in applying 3D CAD systems in the field.

Firstly, for collaboration among several companies to produce one final product using the modular production methodology, it is difficult for the collaborating companies to use the same 3D CAD system because each company's circumstances are different. Therefore, information loss or inefficiency is increased, when the design information is transferred or shared between the collaborating companies.

Secondly, although the same 3D CAD system may be used in all companies, it is difficult to share the design information due to company security policies. For example, a first tier company may not want to share the total design information with a part supplier because this information could be transferred to a rival first tier company. Hence, the first tier company will not provide all the design information to the part-supplier. By properly processing the design information, only the essential information necessary for the part supplier to produce the sub-module will be provided. In this case, a problem of conducting design process repeatedly for sharing design information with part suppliers arises.

Thirdly, to solve the above problems, some companies provide the translated design information represented in a 2D hardcopy drawing or a neutral format such as IGES or STEP based on boundary-representation (B-rep). However, in this situation, if the product design is changed or updated, the related processes for transferring and applying the engineering change are inefficient.

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Lastly, a first tier company can produce full assembly 3D model based on design results for sub-modules from part-suppliers. Because a neutral part model based on B-rep does not contain Datum information, it is difficult to combine that module with master assembly model. In some cases, such ambiguities result in errors. After completing the assembly model design, if a sub-module is changed by an engineering change request, it is inefficient to apply the modified sub-module to the master assembly model again because the sub-module's parametric information has been lost.

In this paper, in order to solve the problems mentioned above and facilitate design collaboration between collaborating companies using different 3D CAD systems, a global top-down modeling approach using a neutral reference model is proposed.

## 2. Related Work

Product lifecycle management (PLM) consists of many technologies which are classified into two categories: activities focused on the business (such as enterprise resource planning (ERP), customer relationship management (CRM), supplier relationship management (SRM), collaborative product commerce (CPC), etc.) and activities focused on the product (such as computer aided design (CAD), computer aided manufacturing (CAM), computer aided engineering (CAE), product data management (PDM), quality function deployment (QFD), failure mode & effect analysis (FMEA), collaborative engineering, etc.) [1]. Besides these two categories, the technology for international standards is also important for PLM, which can have a relationship with the technologies in the two categories mentioned above.

The related technologies of the present study are arranged in Fig. 1. The current research is related to top-down modeling, collaborative assembly design, engineering change management, and standardization.

### 2.1. Top-down modeling

There are two design methodologies for product design using 3D CAD: the top-down modeling and bottom-up modeling approaches. The process flow for the top-down modeling approach is shown in Fig. 2 [2].

The primary characteristic of the top-down modeling approach is that the design process starts from abstract specifications [3]. The abstract specifications can be represented by an abstract geometry, which is transferred to the related modelers. The embodied abstract geometry is called the *framework* or *Layout*. Generally, *layout* is used for representation in 2D domains. Therefore, the embodied abstract geometry including 3D elements for 3D CAD is called 3D layout or skeleton.

Suzuki produced a parametric contour of the shape based

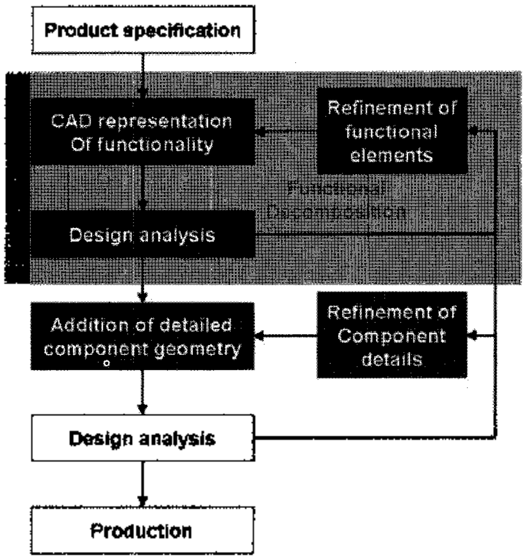


**Fig. 2.** Top-down modeling approach

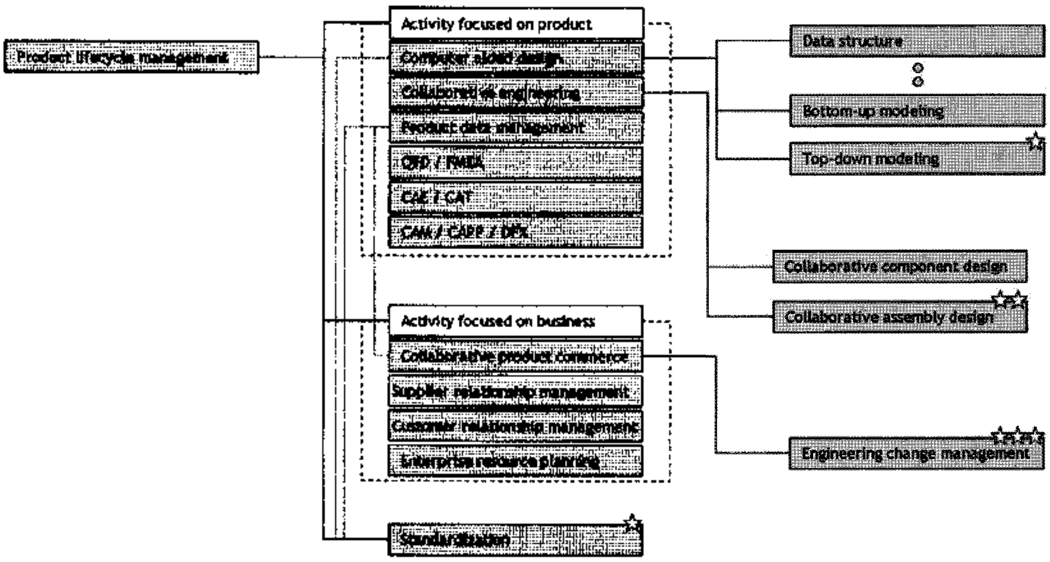


**Fig. 1.** Related technologies of the present study.

on layout [4]. Emmerik [5] provided consistent location information to each CSG primitive using the concept of a *geometric tree*, which provides a local coordinate system based on the parent coordinate system, to each node. This consistent information is called *datum systems*, which is similar to the present Datum CSYS. In this research, top-down modeling approach becomes specialized using the abstract geometry element.

Shah [6] explained the parametric top-down modeling approach using the keyword *skeleton*. This concept is similar to the present commercial CAD systems. The Cambridge Engineering Design Centre (EDC) proposed a generic component, which defines the relationship between the part models, in the functional modeling system. This concept is called *interface*. Although this concept only provides constraints using variables, it is similar to the top-down modeling approach because the constraints defined at the highest level can be propagated to the lower levels.

Guan [7] defined the cubic space for the undefined part using *bounding primitive*. This concept is *geometric configuration space*, which is identical to the present concept of layout.

*Design space* was proposed as a layout by the project report ESPRIT 5168 [8]. On the other hand, Csabai [9] proposed *3D layout*, and, Theodosiou [10] proposed *virtual solid*. These proposed concepts are all similar to each other.

All pieces of research have a common concept of an *abstract element*, but the abstract element can be classified into two categories: *bounding box* and *skeleton*. Although these two concepts have some differences in the initial ideas, after considering the results including all functional requirements, it is the same difference. All of these concepts are combined with the notion of *skeleton model*.

### 2.2. Collaborative engineering

The growth of IT technology and extension of networking capabilities greatly influences general manufacturing technologies. In the product design field, *Collaboration* has been defined and researched under the influence of these. Collaboration is classified into two categories: the concept of business called collaborative product commerce (CPC) and the concept of development called collaborative product development (CPD). Recently, CPD has also been labeled *Collaborative engineering*.

Collaborative engineering can be re-classified into two categories: collaborative component design and collaborative assembly design [11]. Collaborative assembly design is also referred to as AsD [12].

Collaborative component design is used primarily for synchronous design and modeling. For example, it is the essential technology for one part model to be modeled by several modelers in a virtual space. Thus, collaborative component design is focused on real time synchronization.

Collaborative assembly design is used primarily to integrate part models and sub-assemblies, which are modeled by the modeler in charge, into a virtual repository. Collaborative assembly design also provides inquiry and view functions, therefore it is focused on the integration and interoperability of design information rather than real time synchronization.

Maxfield [13] built a virtual environment for real time collaboration among designers using constraints. Chen constructed an assembly model in a virtual environment using an *e-Assembly* system that represents the assembly data model using *collaborative assembly representation* (CAR) [14-16]. Shyamsundar built a *cPAD* system that enables the designers to build an assembly model in a virtual environment using *assembly representation* (AREP) [11, 17]. Kim formalized the general methodology of collaborative assembly design by inserting *joints*, a concept for manufacturing, into the design assembly constraints [12]. Cutkosky researched internet-based tools and design methodology for effective collaboration among distributed collaborating companies through the MADEFAST project. However, the method does not access information from the CAD model, but rather accesses the document information [18].

In all pieces of research above, the assembly model is only realized in a specific system using a specific data format. The research above is primarily focused on the data model for common assembly features and their relations, and the assembly design system is also embodied using the data model which is the result of the research above. The assembly model is one of critical information for the following CAE process, interference check process, and so on. If the relationship with commercial systems is not considered, the system which only includes the function of inquiry and view is not effective for real fields.

Moreover, because an effective solution for transferring and applying the modified design information from engineering changes is barely considered, it is difficult to realize collaboration in the part modeling process.

### 2.3. Engineering change

An efficient management of the engineering change information is important for the collaboration among companies.

Diprima developed an entire framework to control engineering change (EC). The EC process is managed in an environment that considers the connection between several organizations [19].

Wright classified the research for engineering change management (ECM) into two categories. One is for ECM analysis tools; the other is for the methodology that minimizes the influence of ECM from the viewpoint of inventory and production control [20]. Peng formalized the data model for ECM based on ISO10303 STEP [21].

Based on research on the ECM concept, various methodologies to access ECM information have been studied. These methodologies are classified into three categories: a document-based approach, a process-based approach, and a product structure-based approach [22,23]. The product structure-based approach controls engineering change using a product structure managed by PDM, which has been researched by Peng [21] and Do [22, 23].

Recently, Yang [24] transferred the engineering change information to a 3D CAD model, which is newly classified into parameter-based approach. This method extracts the major design parameters from an existing part model, and then the CAD model is changed by modifying the design parameters. However, to apply this method to a real situation, two types of CAD models must be modeled, the general CAD model and the parameter-extracted CAD model, because the parameter extraction process occurs after the detail design process for a part model.

Without IT or network technologies, the document-based approach must be the primary solution for EC. Frank [25] also emphasized the importance of the engineering change management and propagation. However, only the document specification and propagation processes were formalized due to the technological conditions at that time.

Nowadays, various studies are being undertaken regarding engineering change propagation and management. Although the format of engineering change information is either an electric document or an object, a substantial base format is still text-based information specifications, which are similar to the document-based approach.

Aleixos [26] studied collaboration between two different commercial CAD systems, emphasizing the necessity for an effective neutral format of a parametric CAD model for collaborations.

## 3. Neutral Reference Model for EC Propagation

In this research, the top-down modeling approach is applied to different commercial CAD systems to directly enable the propagation of engineering change between CAD models. Although there has been much research on standardizations and neutral formats, there is no research on implementing a neutral format of an abstract element [3] applied to a top-down modeling approach to collaborating companies or different commercial CAD systems. This top-down modeling approach applied to collaborating organiza- tions or different CAD systems is called a *global top-down modeling approach*.

The neutral format of an abstract element consists of two data models. One is a skeleton model using a neutral format for propagating and sharing shapes or geometric information from the CAD model. The other is a data model using a neutral format for representing external reference data. Each part model refers to the skeleton model.

In this research, the former model is called the *neutral skeleton model* (NSM), and the latter model is called the *external reference model* (ERM). The integrated model combining these two fundamental models is called the NRM (*Neutral Reference Model for Collaborative Design*). That is, the NRM is a neutral data model playing the role of an abstract element for a global top-down modeling approach. NRM can be subdivided into the NSM for geometric information and the ERM for external reference information.

In addition, NRM must contain version information. Engineering changes can occur in all related companies; moreover, engineering changes do not propagate through only one way, but can propagate through many ways. However, the information transfer is not settled in real time, but applied when a designer regenerates the related CAD model. Thus, it is important to manage the version information to maintain the robustness of information for the correspondence relationship and external referencing.

### 3.1. Neutral skeleton model (NSM)

The neutral skeleton model only contains datums: the datum point, datum axis, datum coordinate system, datum plane, datum curve, and datum sketch. There is no non-geometric information such as material specifications, manufacturing specifications and tolerance, because non-geometric information can be shared from the solutions of prior research. Only the geometric information is considered in this study.

The geometric information of the neutral skeleton model can be represented by not only the part42 format from ISO 10303 STEP, but also modeling commands provided in a *macro-parametric* approach [27, 28]. The macro-parametric model is proposed to exchange design history information among the commercial CAD systems, which is increasing in demand for commercial use. Because the macro-parametric methodology can represent the modeling history and can be expanded to represent the datum features, it is efficient to implement the neutral skeleton model using the macro-parametric methodology. In this paper, elements of NRM are defined by referring to and extending the datum-related commands provided in the macro-parametric approach.

In detail, the NSM is defined by following procedure:

1. All datum features in all major commercial CAD systems have been analyzed/sorted and information model requirements are established;
2. Datum-related commands, which satisfy the information model requirements, are selected among modeling commands in the macro-parametric approach;
3. Those selected commands are structured and additional entities, complying with the information model requirements, are defined if necessary.

The NSM is diagramed in Fig. 3 with a graphical representation form called EXPRESS-G.

### 3.2. External reference model (ERM)

The ERM represents the correspondence relationship of each skeleton element among a neutral skeleton file, a native skeleton file, and a part file referring to skeleton elements contained in the native skeleton file. The ERM is conceptually similar to mapping tables, as described in Fig. 4.

When an engineering change occurs for an ongoing product, a skeleton file in OEM side is converted into a neutral skeleton file and then native skeleton files in supplier sides should be also changed according to the converted neutral skeleton file. Translation of a native skeleton file in a supplier side is performed using this correspondence relationship. After part models of suppliers are modified, they are sent to OEM and re-assembled in a product model in OEM side. In this re-assembling, the correspondence relationship

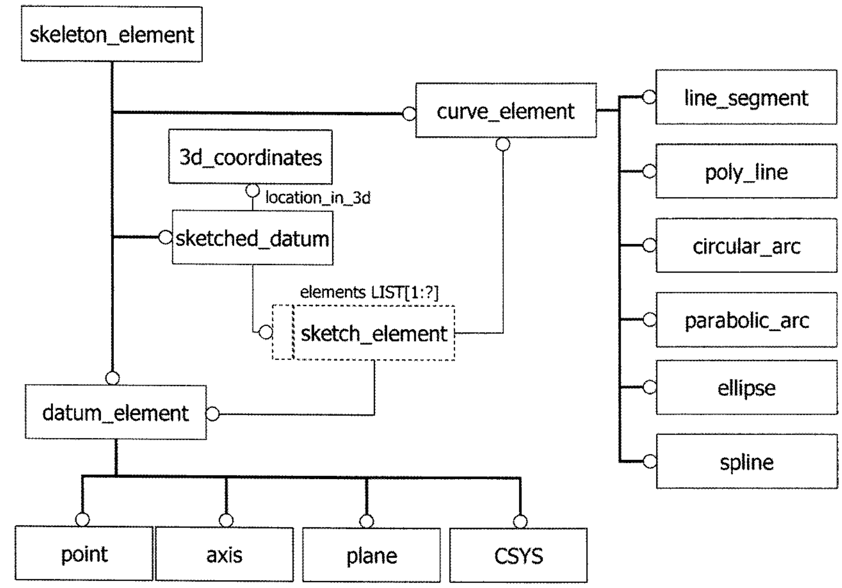


**Fig. 3.** EXPRESS-G diagram for NSM

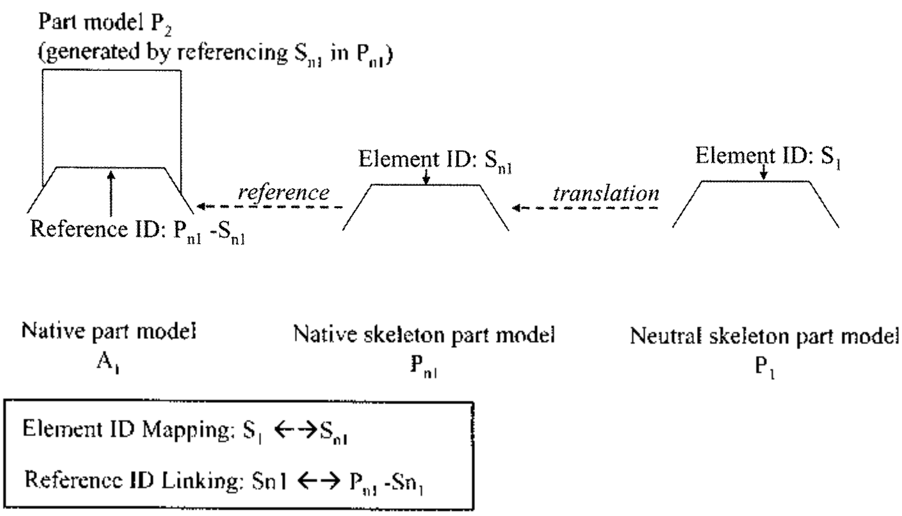


**Fig. 4.** Information contained in the ERM

is also used.

The EXPRESS model for ERM is shown in Fig. 5. The entity, *skeleton_element_mapping*, contains mapping/linking information of one skeleton element among neutral skeleton file, native skeleton file, and native part file. The entity, *reference_element* is used to identify a skeleton element in different models and has *model_name* and *element_name* as its attributes. The attribute, *model_name*, represents a file name. The attribute, *element_name*, identifies skeleton element in a file and its entity data type is *select object*, an entity data type provided in the macro-parametric approach [27,28].

## 4. Implementation and Experiments

In this study, not only is the implementation of NRM important, but also its verification is important because interoperability with commercial CAD systems must be guaranteed. To evaluate the proposed NRM for EC propagation, following design collaboration case is postulated: One first-tier company (OEM) and two second-tier suppliers are engaged in the development of a new power switch. Their responsibilities and CAD systems in use are shown in Fig. 6.

Based on the proposed NRM, a pilot system called *EC Propagator* has been developed and its implementation environments are as follows.

- OS: MS Windows
- Program Language: C++
- CAD System: Pro/Engineer, CATIA
- API: Pro/Toolkit, CAA Automation API
- ETC: MS XML Parser

The *EC propagator* consists of two modules; pre-processor which coverts a native skeleton file in OEM side into a neutral skeleton file and post-processor which translates the

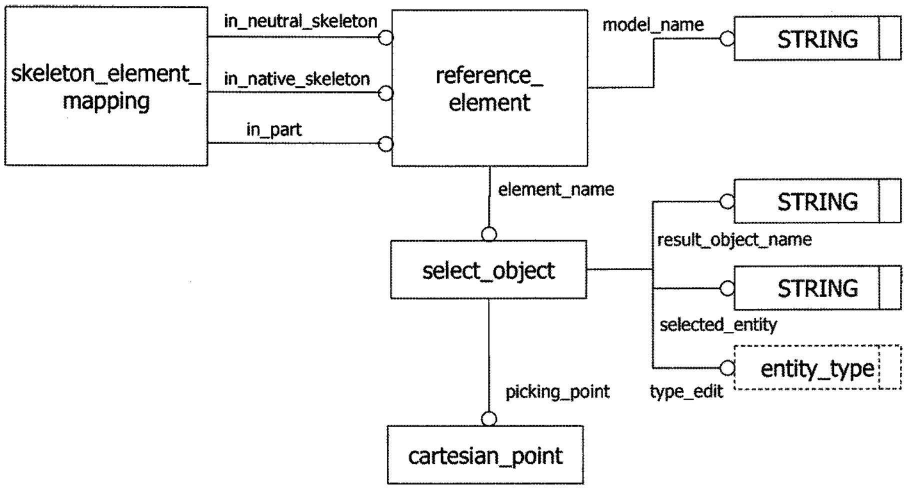


**Fig. 5.** EXPRESS-G diagram for ERM

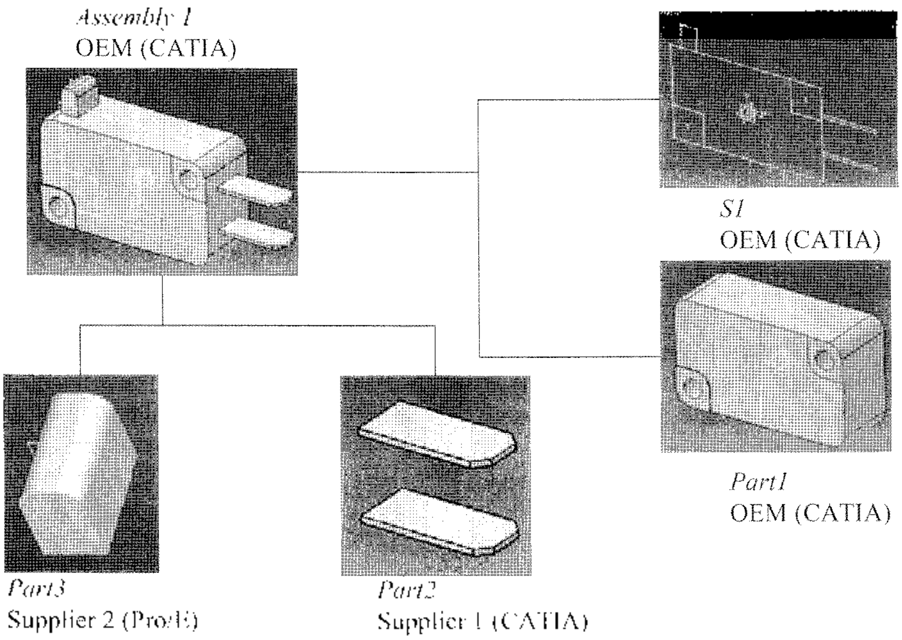


**Fig. 6.** Organization of product development teams and their work responsibilities

neutral skeleton file to a native skeleton file in a supplier side.

EC propagation procedure by using the *EC Propagator* starts with the change of a native skeleton model using its own commercial CAD system in OEM side. The native skeleton model is translated into a neutral skeleton model using the *EC Propagator*. Fig. 7 shows a part of the neutral skeleton model.

The translated neutral skeleton model is then converted into native skeleton models with the same CAD file format used in supplier sides. At this time, an external reference model is also created, storing mapping relationships between skeleton elements in native and neutral skeleton models. Each part-supplier re-designs the 3D CAD model of the part. In this process, semi-automatic change of the part model occurs since designers usually put various types of relations between elements in a skeleton model and a part model such that when an element of the skeleton model is changed, corresponding elements of the part model also changed according the predefined relations. After semi-automatic design change, manual operations by designers are continued. Fig. 8 shows an automatic change of part model in the supplier 2 side in the test scenario.

The revised 3D part model is translated into a neutral part model in STEP AP203 format. At this time, the external reference model is updated, storing linking relationships between skeleton elements in native skeleton and native part models.

Finally, the neutral part models and the related external reference model are transferred to the first tier (OEM) company inversely. Product model is re-assembled through inserting the revised neutral part models. In this operation,


**Fig. 7.** Neural skeleton model generated by the *EC Propagator*

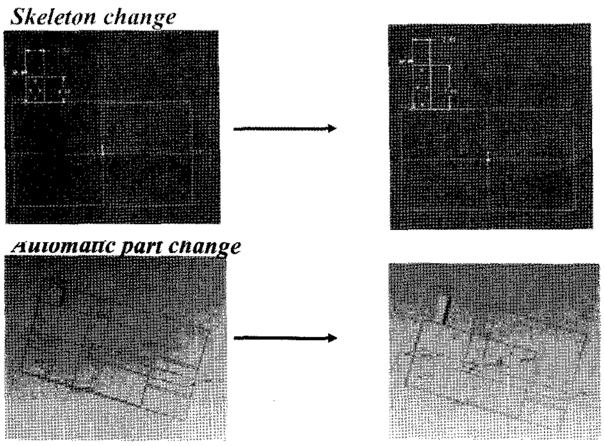


**Fig. 8.** Automatic part change in a supplier side according to predefined relations between skeleton and part models

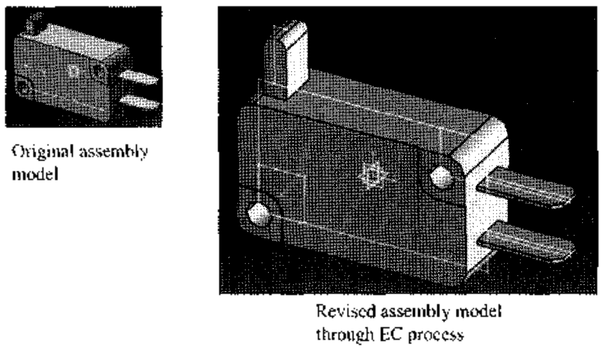


**Fig. 9.** Revised product model after EC in the test scenario

the external reference model is utilized for finding a position to place a neutral part model in the 3D global coordinates. Fig. 9 shows an EC result by utilizing *EC Propagator* in the test scenario.

## 5. Conclusion

Studies related to EC have been conducted by several international consortiums, but the studies have usually focused on the management or administration of EC. By adopting a global top-down modeling approach with a neutral skeleton and external reference models, this study aims to define a new designer-friendly media representing EC information and to automate EC process partially.

To this end, the present study proposes a new method for EC propagation using a neutral reference model among different CAD systems in different companies. This paper also explains following research results: concept of the proposed method; the procedure of EC propagation; the neutral skeleton model; the external reference model; and the pilot implementation.

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